NASA TT F-9715

CEREBRAL ANEMIA AND CONGESTION, MECHANICALLY PRODUCED IN ANIMALS BY VERTICAL POSITION OR BY GYRATORY MOTION

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Translation of "De l'anémie et de la congestion cérébrales provoquées mécaniquement chez les animaux, par l'attitude verticale ou par un mouvement giratoire".
Physiologie Expérimentale, Vol.3, pp.251-272, 1877.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON OCTOBER 1965

CEREBRAL ANEMIA AND CONGESTION, MECHANICALLY PRODUCED IN ANIMALS BY VERTICAL POSITION OR BY GYRATORY MOTION

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Protracted maintenance of various body positions, in its influence on blood circulation in the brain, was investigated in human and animal experiments, with recordings of respiration and cardiac stroke volume. Vertical position, with elevated head, resulted in progressive reduction of respiration and cardiac rhythm, ending in syncope and death due to bulbar anemia. Vertical position with the head downward resulted only in minor symptoms of congestion. Restoration to horizontal resuscitated the animals from apparent death. In centrifuge tests, position of the head toward the center produced death within a few minutes, while the animals survived for twice this time in the inverse position. Recumbent position in human subjects was found optimum for preventing syncope or suspension of cardiac action under extreme stresses.

Author

INTRODUCTION

Man passes his life, alternately in vertical and horizontal attitudes. These changes in position succeed each other without producing any apparent disorder in the organism. At least, this is true for a generally healthy state of the individual; however, it is generally known that disease, debility, or

* Numbers in the margin indicate pagination in the original foreign text.

prolonged recumbent position or, even more so, a combination of all these factors, may render rapid alternations of attitude highly dangerous and even fatal.

In some anemic subjects, the transition from horizontal to vertical position never remains without symptoms; thus, such persons are always in a state of lassitude during the first few hours after arising in the morning*. In these subjects, raising the head after it had been lowered for a few moments, will /252 cause vertigo and even actual syncope.

These events, as they are encountered in convalescents and in anemic individuals in the erect state, are all due to the same cause, namely, to the influence of gravity. In fact, gravity exerts quite a different influence on the blood flow, depending on the position of the body. When the body is horizontal, gravity acts in equal force on all parts of the organism.

In the upright position, which is the usual posture for man, gravity acts differently on the blood stream in the various regions of the body. It is well known that, for the supracardiac regions, the pressure of the arterial blood is diminished by the effect of gravity whereas it is increased in the infracardiac arteries. In addition, Rameaux was quite justified in mentioning the difference produced by gravity in the diameter of the capillary vessels: The capillaries in the inclined or sloping regions are dilated by the high blood pressure at their interior, a dilatation which results in a more rapid circulation within these vessels. Thus, despite the obstacle offered by gravity to the venous blood flow in sloping parts of the body which, at first sight, would have a compensating and neutralizing effect on the favorable influence of gravity on

* It has been found that some individuals actually have to be in a horizontal position for doing any intellectual work, and numerous learned persons are known who were unable to work in any other position.

the arterial blood flow, it seems certain that the downward slope has a dual effect on the circulation: Not only will an inclined organ contain more blood but the blood itself will circulate more rapidly there. Inverse reasoning indicates that, in the upper regions of the body, the blood volume will be less and the blood will circulate more slowly there. However, this influence is supplemented by the contractility of the small vessels, which somewhat attenuates the effects of mechanical forces by producing an adaptation to the arterial pressure. As soon as too high a pressure tends to dilate the small vascular networks beyond a critical value, the contractility of these vessels comes into play and counteracts this cause of dilatation. When the arterial pressure drops below a certain value, the small vessels relax beyond the normal degree and permit continued circulation of the blood despite a diminution in its impulsive force. However, this adaptation of vascular contractility must be maintained by variations in blood pressure. Thus, after prolonged decubitus, a dual phenomenon is produced as soon as the subject changes to an erect position, namely, cerebral anemia together with congestion of the legs, due to the fact that /253 the disaccustomed vessels no longer counteract the effects of gravity (Bibl.1).

It is the merit of Piorry to have been the first to emphasize this extensive influence of gravity on the circulatory system in the organism in general and in the encephalon in particular (Bibl.2). This author thus counteracted the concept by Bichat who had maintained that any syncope was always due to a suspension of cardiac action. Piorry, without contesting the possible existence of syncopes linked to cardiac failure, was of the opinion that very often a syncope is only the result of a decrease or a complete failure of encephalic action. He stated that the position of the patient can be considered a criterion for diagnosing apoplexy and cerebral anemia in cases of loss of consci-

ousness.

In addition, Piorry ran several important experiments as to the influence of gravity on the circulation in the dog, experiments which need not be recalled here. This author first opened the jugular veins of the animal until the heart beat was no longer perceptible on palpation and until complete arrest of respiration, with suspension of sensation and motion, occurred. "If, in this state of apparent death, the hind part is raised while keeping the head low, respiration will immediately be restored, the heart will start contracting, the head which had been lolling will raise, the paws will lift, and the cephalic action will resume." The author then mentions the counterpart of this experiment, describing it as follows: "If all parts of the body of the animal, revived by lowering the head, are kept in the opposite position for several minutes (Bibl.3), all accidents will reappear, and the syncope will ensue".

Marshall-Hall (Bibl.4) later confirmed the concepts formulated by Piorry.

A large number of authors adhered to this direction, and it is generally /254 agreed today that cerebral anemia must be responsible for the mechanism of syncope, when passing from a recumbent to a vertical position.

It can be proved directly that turgescence is produced in the vessels of the encephalon on inclining the head. We have observed this ourselves, in experiments on newborns and on trepanned animals (Bibl.5). If this particular position is prolonged for some time, congestive phenomena will result.

We made an attempt to define the effects of changes in cerebral circulation on the respiratory and cardiac motion*.

* Our experiments, in opposition to those performed by Piorry, concerned intact animals. (We should mention that, from the static viewpoint, these animals organized to live horizontally naturally are not subject to the same conditions as man. However, man will be exposed to highly similar conditions if, after protracted recumbent position, he will have lost the habit of standing erect.)

Not only were we able to provoke blood derivations in the animal, in favor or in disfavor of the encephalon, by modifying its position but we also were able to exaggerate these further by making use of the centrifugal force.

We will review these two experimental methods, discussing first the effects produced by posture and then those produced by the influence of gyratory motion. The main results of our research have already been printed in a recent paper published by the Academy of Sciences (Bibl.6).

I. INFLUENCE OF THE VERTICAL ATTITUDE ON THE ENCEPHALIC CIRCULATION /255

In a highly interesting thesis, submitted by A.Regnard in 1868 (Bibl.7), we read a description of two experiments made on trepanned rabbits, which were successively placed into two opposite positions, with the head raised in the one case and lowered in the other. After leaving the animal for five minutes in the second position, the above author found that the sensibility had remained intact whereas, at the end of two minutes, it had completely disappeared when the head of the animal was raised. The respiration was short and jerky, and the animal appeared to be in syncope. The author did not continue this particular experiment.

However, we were furnished with the results cited by him* and took in mind then to verify these data.

In the course of our experiments, last year, on the motion of the brain, performed in the laboratory of Prof. Marey, we reconstructed the experiment described by A.Regnard on two trepanned rabbits of our own. Instead of leaving

* It is generally known that rabbits are usually carried by holding them by the ears; there is no known case of an animal having died from being held in this manner, a position in which they are frequently maintained far beyond two minutes.

the animals for two minutes in a vertical position with elevated head, we left them in this attitude for ten minutes. Nevertheless, no unusual phenomenon was observed and the animals retained their entire sensibility, making us believe that the above author had been wrong or that possibly an error was committed during his experiment.

We therefore abandoned this particular question at that time; however, a few weeks later, we were again confronted with the same problem, under the following conditions: We had applied a large trephine to the cranium of a rabbit; since an osseous hemorrhage, following this operation, prevented us from /256 studying the cerebral oscillations, we placed the rabbit in a vertical position so that its head was higher than the rest of the body. When we wanted to pick up the animal after a few minutes we saw that it had died. Neither the traumatism nor the hemorrhage seemed sufficient to explain this death, so that we were led to conclude that death might well have been caused by the same factors that had produced the syncopal manifestations in Regnard's rabbit.

Therefore, we resumed these experiments by operating on trepanned rabbits. The theory indicates that, in fact, the vertical posture will produce, within the cranium and over the intermediary of the cerebrospinal fluid, an aspiration on the encephalic vessels which presumably counterbalances, within certain limits, the effects of gravity.

Considering the general layout of the craniospinal cavity, it is quite obvious that, in the vertical position, the fluid within this cavity will tend to flow toward the sloping parts. To have such a displacement actually take place, it would be necessary that the cranium sink in, while the upper part of the rachidian axis would dilate.

Moreover, Prof. Richet has demonstrated that the vertebral channel is

dilatable and that a certain quantity of the cerebrospinal fluid may become lodged there while this cavity is already full, with this fluid pushing back the blood of the rachidian plexus venosos whose walls are depressable. On the other hand, the cranium cavity is not rigid in infants whose fontanels have not yet closed or in trepanned animals. In these subjects, in the vertical position, a concavity of the fontanels is observed or else a depression of the dura mater, indicating a reduction in volume of the intracranial organs: There is /257 no doubt that this decrease could not take place in the case of complete occlusion of the cranium*. It is certain that this reduction means a less extensive distention of the vascular element, but it is also certain that, from the side of the cerebrospinal fluid, a displacement may have taken place from the cranium toward the vertebral column. This results from the extensibility of the rachidian cavity, which we will discuss later.

In the case of complete integrity of the cranium, the tendency of flow from the spine remained in the state of pressure reduction or so-called virtual vacuum, and could have occurred only under the condition that a larger quantity of blood had penetrated into the encephalic vessels.

Thus, we can consider that the effects of gravity on the cerebrospinal fluid column acts in the manner of a siphon which tends to counteract, more or less efficiently, the causes of cerebral anemia no matter of what origin: action of the gravity on the arterial and venous circulation of the brain, vascular contractility, etc.

Finally, the vertical posture, by dilating the vessels of the sloping body parts, produces an accumulation of blood in these parts which acts in the manner

* This depression of the brain level, in vertical position, had been observed several years ago by Marey on a patient, of the Lorain Service, who had a scar on the forehead covering a large loss of bone substance (Bibl.8).

of a phlebectomy or of a Junod ventouse, for lowering the blood pressure in the upper regions.

1. Vertical Position with Raised Head

The animals kept by us in this particular position were fixed in two different ways. In some experiments, they were simply suspended by the ears and in others, more often, they were strapped to the board usually employed in the experiments, with their head retained in a Czermack harness. At times, a strap was tied around the abdomen so as to prevent excessive relaxation of the abdominal walls under the influence of the weight of the viscera.

A dual cardiac probe*, maintained around the thoracic cage, permitted, during the entire experiment, the recording of cardiac and respiratory traces.

During the first few minutes, usually nothing remarkable was observed; /258 it generally took 10 - 20 min before a slight reduction in the cardiac rhythm could be detected on the graphic traces, accompanied by a minor decrease in respiratory force. These symptoms become increasingly more pronounced: The cardiac frequency and specifically the respiratory frequency diminish progressively. At the same time, some external phenomena are observed, that gradually increase in extent. These include pallor of the conjunctiva, of the nictitating membrane of the nostrils, and of the buccal mucosa. The respiration continues to drop and to diminish in amplitude, accompanied by an increasing weakening as indicated by the pulsation trace of the heart.

At this time, the sensibility is already extensively blunted, in that the animal hardly responds to any exterior stimuli.

This is soon followed by manifestations that could be considered as a

* For a description of the instrument, see Marey (Bibl.9).

prognostic of imminent death. The body of the animal is shaken by convulsions. These convulsive phases are succeeded by periods of quiescence, during which the respiration and the heart systoles continue to decrease in force and frequency. Occasionally, the convulsions produce a momentary acceleration of the cardiac rhythm which, however, is of short duration.

The animal then becomes insensible, its muscles relax, and it is unable to contain its urine. At this instant, the respiration rate of the animal drops to 2 - 5 times per minute*, after which it ceases entirely. The heart beat has decreased progressively and frequently is intermittent. Nevertheless, the heart continues to contract even after respiration has stopped, and the graphic curve produced over a time of two minutes or even more after complete arrest of respiration traces cardiac systoles although at large intervals. The diagram in Fig.125** shows a typical case of gradual decrease in cardiac and respiratory movements.

The lowest line in the diagram (curve 1) corresponds to the tenth minute /259 of the experiment. At this instant, the respiration is still rapid and strong; to a large degree, because of its fullness, it masks the curve of the heart beat which, however, is quite distinct at the end of each expiration. (The ascending branch of each of the large respiratory waves corresponds to the inspiration of the animal while the descending branch corresponds to the expiration phase.)

The next curves (2, 3, 4, 5) represent modifications of the cardiac and respiratory rhythm, recorded every five minutes. The second curve already shows

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* These final respirations usually are purely of a diaphragmatic type with the ribs remaining motionless.

** The illustrations are not included here, since they are not reproducible. Titles are assembled at the end of the text.

a noticeable reduction in respiratory force.

The drop in amplitude and frequency of the respiratory movements becomes continually greater; the heart beat decreases and finally becomes undulatory /260 (curve 6).

This weakening is more pronounced in the upper curves. The curve before the last (curve 7) corresponds to the convulsive period, clearly indicating that the first pulsations in the trace, because of the incipient convulsions, exhibit an instantaneous acceleration and irregularities that are followed by a distinct deceleration. The respiration is hardly discernible.

Finally, in the last curve, respiration is stopped completely; the heart systoles, although widely spaced, still show as faint undulations.

These traces were obtained on an animal that took 45 min to die.

In a general manner, death occurred on the average at the end of 30 to 45 min. Three times, death occurred in less than 15 min. In other cases, death intervened only at the end of 90 min and even as late as 135 min after start of the experiment. The basic point is that in all of these cases, without exception, the outcome was fatal for the animal.

In checking on the arterial pressure of some of our experimental animals, we found a decrease in carotid pressure and an increase in femoral pressure, at the instant at which the animal was positioned with its head elevated. At the end of a variable time, the pressure dropped in all the arteries. During the convulsive phase, a rather large pressure rise was observed which followed a period of stationary values, at the end of which the pressure dropped gradually to zero while the heart still executed, for a few moments, minor oscillations.

It is of interest to define the mechanism according to which death always intervened in rabbits whose head had been elevated above the rest of the body.

The aspects discussed at the beginning of this paper make it unnecessary to repeat here what we said on the role played by gravity in the production of these accidents. However, it seems quite obvious that a cerebral anemia is the main cause of the syncope and of the death in this particular case. We are /261 not even speaking of the pallor of the buccal and nasal mucosa or of that of the conjunctiva, since one could easily object that facial anemia does not necessarily imply anemia of the encephalon. Therefore, we prefer to restrict ourselves to the state of the encephalon itself whose pallor and reduction in vascular caliber are clearly defined, following change-over to the erect posture. This was easily demonstrated on trepanned animals if the cranium was restored to its normal rigidity by closing off the skull with a window applied in accordance with the Donders method.

Theoretical considerations and observed facts make us believe that encephalic anemia not only leads to a destruction of the sensibility and motility but also, in this specific case, forms the starting point for the slow-down and, later, for the complete arrest of respiration and of cardiac action, in which case bulbar anemia would be sufficient to explain both consequences*.

The convulsions, reported earlier by Kussmaul and Tenner, as the final manifestations in their experiments on the effect of hemorrhage and encephalic artery ligature, also speak in favor of a bulbar anemia.

Before appearance of the convulsive phase, while respiration and heart rate are already quite reduced in volume, it is sufficient to return the animal to a horizontal position to have the cardiac systoles immediately increase in

* It should not be forgotton that, while encephalic anemia acts as the primary cause in decreasing the strength and number of systoles, this weakening of the heart at decreasing number of beats, in turn, results in a decreased quantity of blood fed to the encephalon; these phenomena interlink and exert a mutual influence.

frequency and strength and to have the respiratory movements resume their normal rhythm. This is clearly shown in Fig.126, where the first curve corresponds to the vertical position. In addition, the diagram - although very faintly - shows the trace of heart beats intermixed with the respiratory curves.

As soon as the animal is restored to a horizontal position, its respiration increases immediately in frequency and the cardiac systoles, resuming their original intensity, are clearly defined on the trace of the lower curve. /262

Even after the animal has passed the convulsive phase and after its respiration has dropped to almost zero, it can be revived by restoring it to a horizontal position. Surprisingly, the frequency of respiration resumes immediately, showing in a striking manner the sudden return of the arterial wave with its original strength of impulse, in the encephalic vessels.

Figure 127, which gives the respiratory trace of a rabbit at the point of death in a vertical position, indicates the favorable and sudden influence exerted by a horizontal position, to which the animal was returned at the point H.

As soon as the animal is in this new position, its respiration becomes more frequent and deeper.

However, this recovery is not very stable since it is sufficient to return the animal to a vertical position for an immediate cancelation of the beneficial effects of a horizontal posture to take place, just as rapidly as these effects had appeared previously. This new experiment represents an exact /263 counterpart of the preceding experiment, as shown by the tracing in Fig.128.

Immediately after raising the head of the animal, the respiration drops steeply, becoming slow and extremely weak.

In cases in which the respiration had come to a complete standstill or in

which the heart beats were no longer perceptible to the touch, we were frequently able to resuscitate the animal by compressing its thoracic cage in a rhythmic manner, so as to simulate the respiratory movements, while simultaneously restoring the animal to a horizontal position or - still better - lowering its head toward the ground and raising its hind part.

At the end of a few moments, the respiration resumed spontaneously and the cardiac systoles returned to their former strength. However, the animal remained completely inert for a relatively long time. Even after being unstrapped, it remained in its previous position and hardly reacted to stimuli. These symptoms disappeared gradually, at a rate which depended more or less on the individual animal. Ordinarily, the animal had completely recovered in less than one hour.

This peculiar state, exhibited by the animals after an excessive length of time in a vertical position, may be due to two causes which it should be interesting to determine experimentally. The brain may become congested just as it can happen to any organ that had been anemized either due to an elevated position, by compression, or by temporary obliteration of its arteries.

On the other hand, disorders of this type may be caused by a compression /264 of the brain, due to a hypersecretion of cerebrospinal fluid. It is known from Donders' experiments, that this fluid is readily absorbed and secreted, depending on whether the intracranial pressure decreases or increases.

To some extent, the cerebrospinal fluid adapts itself to the cerebral volume in such a manner as to occupy - at a moderate pressure - the space that the nervous and vascular mass leaves free in the cerebrospinal cavity.

We made experiments on dogs to check the influence of vertical posture with the head upward. We expected that this species would be much less sensi-

tive than the rabbit to the effects of declivity, since we had previously found that the dog frequently shows a high resistance to ligature of the two carotid and vertebral arteries*.

In fact, it happened several times that we kept the dogs in a vertical position with elevated head for a period of four hours, without observing any disorders, except for the natural agitation of any animal when strapped down. However, in two cases vomiting occurred which probably was due to cerebral anemia. It would be of interest to study the effects of posture on various species of animals.

2. Vertical Position, with Head Down

The vertical position, opposite to the preceding attitude, in which the hind part of the animal is elevated, results in an increase of the arterial blood influx toward the encephalon, due to the effect of gravity. Experiments on trepanned animals showed congestion of this organ, no matter whether the animal had its brain exposed or covered by a transparent window which closed off the cranium cavity.

Subjecting the rabbits to this position, we were able to maintain them in this attitude for several hours without inducing death. The animals were restless on occasion, but the circulation and respiration were not impaired; at most, the latter was slightly accelerated. The sensibility of the animals remained intact.

The face of the animal constantly showed the typical signs of congestion. The palpebral conjunctiva and the nictitating membrane** were intensely red and

* See our paper on cerebral motion (Bibl.10).

** In these experiments, as little as in the previous experiments, (cont'd)

injected: the buccal and nasal mucous membranes also were a vivid dark red. However, apart from these external phenomena, the animal showed no major symptoms of any kind.

In one rabbit, we extended the experiment beyond six hours. At the instant at which we removed the straps from the animal, it started walking and then began running, accepting food when offered.

The astonishing difference in the results obtained in our experiments, in which the encephalon was anemic in one case and congested in the other from exactly the same cause, namely, gravity, seems to substantiate the opinion held by many modern authors who deny that cerebral congestion is a morbid entity, although they do not contest its validity as a symptom*.

II. GYRATION

In the experiments, described below, we produced a derivation of the blood away or toward the encephalon, by replacing the influence of gravity with a /266 force that could be intensified readily, while still varying it at will, namely,

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(cont'd) we did not report the state of the pupil where the variations were highly contradictory and even completely in opposition to any theory. We will resume this particular point in a later study, by using the Dandolt pupillometer, so as to be sure of our measurements.

* The way of life of man is conciliable with vertical positions with the head downward, as proved in numerous examples in circuses and market squares. Nevertheless, as observed by A.Regnard (loc. cit.), it is difficult to imagine a more effective cause of encephalic congestion in human subjects. This particular position may even be maintained over several hours without fatal outcome, as proved in a recent case that happened in a village in Bretagne. A workingman who had to repair the cross on the church tower, broke his harness, lost his balance, and remained suspended in space by one foot for a period of three hours before he was rescued. It is true that exactly the opposite occurred in an athlete who, while suspended by his legs from the trapeze in a Florence circus, remained in this position for such a long time that his partners suspected that this was no longer voluntary. After removing him from the trapeze, it was discovered that he was dead. In this case, death no doubt was due to cerebral hemorrhage, promoted by congestion of the brain.

centrifugal force*.

To develop this force, we used equipment previously employed by Prof. Marey in his research on the flight of birds. The device consists of a central metal shaft, supported by four solid wooden posts. Near the upper extremity of this fixed shaft, a pulley block is attached which rotates about itself and is placed in motion by an endless belt, ending in the flywheel of a Bischop gas motor**.

To this pulley block, which rotates about the vertical axis of the equipment, we attached a board of 1.5 m in length whose center was traversed by the shaft. The animal was placed on one half of this board.

For recording the respiration, we applied a process previously used by Marey for recording movements, independent of operation of the unit. The shaft in this device is hollow and open at the bottom, so as to connect with a lever drum over a rubber tube. The respiratory movements and the heart beats of the animal were transmitted across a side tube, communicating with the hollow space of the shaft.

The speed of the motor was regulated in such a manner that the equipment, which always rotated from left to right, had a constant speed of 75 rpm, i.e., one and a quarter revolution per second, so that the conditions of various experiments could be satisfactorily simulated.

In some cases, the head of the animal was placed close to the center /267 of motion and in other cases it was directed toward the periphery. In both

* Let us recall that Darwin (Bibl.11) had conceived a gyratory apparatus, known as a rotating bed, of which he described the design and suggested application to human subjects, placing the head of the patient on the periphery of the device so as to induce sleep, in accordance with the ideas of that time. By placing the head in the vicinity of the center, so as to reduce the cardiac action, it was believed that fevers could be cured. We do not believe that such a device has ever been used on human subjects for therapeutic purposes.

** For a description of this motor, see elsewhere (Bibl.12).

cases, by spinning the animal only a few instants, phenomena of vertigo were observed which were analyzed by Purkinjé, de Graefe, Czermack, and Breuer, whose work has been reported by Prof. Mach of Prague (Bibl.13) who also studied these phenomena on animals and, specifically, on himself.

After spinning a rabbit for a few moments and then placing it on the ground, the animal will execute one or several movements in exactly the same direction of rotation in which it had been spinning previously, as we frequently have observed ourselves. Mach attributed these phenomena, as well as the convulsive movements of the head and eyes, to a displacement of the endolymph in the semicircular canals of the labyrinth, comparing these accidents to those reported by Flourens in his experiments made on section of the semicircular canals. According to Cyon (Bibl.14), this theory is not tenable since he found that these phenomena, determined by a gyratory movement, persist even after section of the two acoustic nerves.

Without further discussing these manifestations at the beginning of gyratory motion, we will proceed to the phenomena observed up to death of the animal, which always occurred no matter whether its head was close to the center or in the opposite area, provided that the rotation was continued for a sufficiently long time. Only, whereas death occurred in the rabbit on the average after 6 - 15 min in the first position, the time was much longer - generally at least double - when the animal had its head directed toward the circumference.

Similarly, with the head placed at the center, death occurred after 10 min in one dog and after 25 min in another dog, while two other dogs which had been placed in the opposite position died only after 45 - 55 min. /268

Here, the phenomena are more difficult to follow than in our experiments on posture, since the rotational motion prevented an accurate observation of

the animal, so that it was not always possible to even define the instant of death unless a graphic recording of the respiration was available. This latter, in the case in which the head was close to the axis of the centrifuge, showed a series of changes analogous to those observed by us in animals placed in an erect position.

The respiration decreased gradually, progressively losing its strength. This was followed by convulsions and by a still greater deceleration of the respiratory movements, which stopped completely shortly thereafter.

Figure 129 shows the respiration at the beginning of the experiment (lower curve), during the convulsive phase (center curve), and a few moments before death (upper curve).

We had in mind to plot also the trace of the heart systoles, but minor oscillations inherent to the operation of the equipment made it impossible /269 to obtain a faithful reproduction.

In animals whose hind part is directed toward the periphery, death by cerebral anemia occurred due to derivations that tended to propel the blood into the upper extremities, draining it from the encephalon and the thoracic organs.

As in another experiment, death intervened in this case exactly like in another experiment, which we repeated on the rabbit or on the dog, whose lower extremities and abdominal region were enclosed in a container, closed off at the level of this region by a rubber sleeve. On exhausting the air from this apparatus by means of a vacuum pump, the animal died soon thereafter because of an excessive flow of blood into the parts enclosed in the container, which acted like a Junod cupping glass.

When the head was on the periphery of the gyrating apparatus, death oc-

curred generally much later than in the opposite case; this can be explained in part by a stasis of the blood in the encephalon*. It must not be forgotten that, although the arterial blood flow toward the brain is greatly facilitated in this position, the return flow of the venous blood toward the heart is considerably inhibited. The brain is congested to the extreme limit and, in addition, the blood can no longer "renew itself" in this organ. The lungs, located not far from the periphery although they are somewhat closer to the center, are also greatly congested with blood. Finally, the heart has difficulty in overcoming the aortic pressure and cannot empty its content into the vessels of the abdominal regions or into the lower extremities.

The autopsy, performed immediately after the experiments, fully substantiated this opinion. In fact, in the last case, the brain as well as the meninges showed extreme congestion; a mere section of the skull bones was sufficient to produce a massive flow of blood; also the lungs were highly congested.

When death was caused by derivation of blood into the hind part, it was /270 found that the encephalon and the meninges were highly anemized. The muscles of the body extremity, placed toward the circumference, were red and bleeding, contrasting with the pallor of the muscles in opposite regions of the trunk. These results were obtained in a distinct form only if, immediately after death (as done by Burrows), a ligature was placed around the neck of the animal to prevent shifting of the blood.

CONCLUSIONS

I. The vertical attitude, combined with elevation of the head, resulted

* It is quite unnecessary to mention that, in this case, the mucous membranes of the facial openings were the site of an extremely pronounced congestion, with the eyes protruding far from their orbits.

- after some time - in the rabbit and possibly also in other animals in a slowing and progressive weakening of the respiration and the cardiac rhythm, as proved by various graphs. At the same time, some accessory phenomena were observed such as pallor of the buccal mucosa, the nasal mucosa, the conjunctiva, etc.

II. Syncope occurs soon thereafter, with the animal losing consciousness, in which case repeated convulsions indicate the possibility of bulbar anemia.

III. These convulsions are rapidly followed by complete arrest of respiration; this standstill precedes that of the heart which occurs soon thereafter.

IV. On the average, death intervenes after about 30 to 45 min, under /271 these conditions. The shortest time observed was 15 min and the longest was more than two hours.

V. Even after respiration had stopped completely, the animal could be resuscitated by placing it in a horizontal position or, preferably, with the head downward.

VI. The opposite vertical position, namely, with the head of the animal pointing toward the ground, is not incompatible with life and may be prolonged for long periods of time without the animal, whose sensibility and motility remain intact, presenting symptoms other than those of exophthalmia, distinct redness of the conjunctiva and of the nictitating membrane, etc.

VII. By substituting centrifugal force for the force of gravity, much more rapid blood derivations can be produced, resulting in either anemia or congestion of the encephalon, depending on the position of the animal. A device, executing uniform rotational motion about a vertical axis, was used for this purpose in which, in addition, the motion was supplemented by recording of respiratory curves.

VIII. Death intervenes within a few minutes, in animals such as the dog, the rabbit, and the guinea pig, if the head is directed toward the center of the centrifuge.

IX. Death still occurred, but only after a much longer time which, in /272 general, was at least twice that of the previous period, if the head of the animal was turned toward the periphery.

X. The same force applied alternately in two opposite directions, resulting in a blood derivation away from the encephalon in one case and toward the encephalon in the other case, will produce a cerebral anemia - other conditions being equal - which rapidly leads to death in the first case, as shown in posture and gyration experiments. In the second case, a cerebral congestion which was not fatal was observed after a much longer exposure time, as proved by the innocuity of the posture experiments under these conditions and the prolonged duration of the centrifugal motion, before ending in death of the animal.

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